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# DYNAMIC STRUCTURAL AND MODAL ANALYSIS OF TYRE COUPLING ON UNSTRUCTURED MESH

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## ABSTRACT:

The coupling is one of a key component of power transmission systems where it is subjected to highly fluctuating loads resulting in over-stressing undesired vibration and shocks. Tyre coupling have capability to absorb sudden jerks and vibration, therefore, it provides safe and efficient operation. In this research, transient structural and modal analysis of tyre, coupling is carried out by using ANSYS structural code on unstructured mesh. To predict deformation, stresses as well as natural frequencies of structure under time-dependent loads to avoid structure failure and resonance. Unstructured mesh is used to reduce discretization error. Research results reveal that the existing tyre coupling design is safe from strength and vibration point of view but it undergoes very large deformation which becomes major cause of fatigue failure. It is also concluded that there is enough potential of weight reduction is available in existing design of coupling which increase system performance.

**Keywords:** Tyre coupling, transient structural analysis, modal analysis and fatigue failure.

## INTRODUCTION:

The couplings are widely used in various engineering applications for power transmission and to increase shaft length to achieve intended function. Shafts are usually available in length varying from 6 to 10 meters, so that they can be easily handled, transported and precisely manufactured. But in most of engineering applications shafts of large lengths are required to transmit the torque which can be obtained by joining two or more shafts in order to obtain the required length (Patel, Oza, Gohel, Parmar, & Kadivar, 2014) & (Johnson, 1996). Then coupling is used to get required length, for that purpose several types of coupling are used, tyre coupling is one of them. Tyre coupling is used to connect two shafts which are co-linear; it will make up the misalignment and withstand the backlash. Since misalignment during assembly can be reduced but can't be eliminated. Misalignment is major

problem in most of application several research are being conducted to detect and analyse its cause and remedies (McGinnity & Mancuso, 2005; Veale & Roberts, 2011). Study is done to detect misalignment between motor and load developed. The developed model equation shows that because of misalignment forcing frequencies come even multiple frequencies of motor speed (Xu & Marangoni, 1994). (Sekhar & Prabhu, 1995) modelled rotor-bearing system to understand effect of (Bossio, Bossio, & De Angelo, 2009). In order to understand the effects of shaft misalignment and rotor unbalance, a theoretical model of complete motor flexible coupling rotor system is misaligned and location of coupling along shaft is determined by using finite element method. Study concluded that coupling location with respect to bending mode shape affects vibration.

Misalignment and unbalance have got extreme focus in design of high speed rotating machinery because they experience unwarranted vibrations and torsional stresses. To get rid of this phenomenon we need a coupling with appreciable elasticity and flexibility. Study was conducted on design and life enhancement of structural components of an aircraft by using flexible coupling, (Nagesh, Basha, & Singh, 2015) and the effects misalignment of jaw, flexible and rigid flange coupling is analysed experimentally by frequency spectrum of unbalance of shaft coupling and compared with available literature and experimental results are very close to them (Pathan & Khaire, 2014). As from above literature, it is concluded that misalignment, as well as vibration, are until serious issues. To solve these types of problems tyre coupling offers intangible benefits through taking angular misalignment, parallel misalignment and absorbing torsional vibration. Tyre coupling is sometimes called self-aligning coupling (Vibration control, 2015).

## 1. RESEARCH AIMS:

Despite of all these benefits and providing solution to such serious problems tyre coupling is remain less area of interest for designers. Therefore, in this research, very little effort is done to bridge this gap. Research is conducted to analyse the behaviour of tyre coupling under transient loading to get knowledge about structural integrity of coupling and potential of weight reduction. Finally, various structure parameters such as deformation stresses as well as on natural frequencies are analysed through finite element method.

## 2. RESEARCH APPROACH:

In order to carry out tyre coupling simulation, three-dimensional models are developed in Pro-engineering software. Model is developed according to given specification. All the three components are first modelled in Pro-engineering modelling than they are assembled. In order to carry out structural analysis, finite element discretization method is used to completely discretise physical domain. Simulation is conducted on unstructured mesh by using tetrahedron mesh elements to reduce discretization error. Patch conforming algorithm is used to refine mesh at critical points and to obtained high orthogonal mesh quality. Transient structural analysis of tyre coupling is carried out in ANSYS 12.0 structural code. Material for flange and tyre are Grey Cast Iron and Neoprene respectively.

## 3. FEA GOVERNING EQUATIONS

Finite element analysis is a numerical technique which solves complex continuous structural problem by discretising into small segments known as element. All the elements are connected at one point

called node, in between two nodes the element is considered as elastic spring. The whole system behaviour is governed by following governing equations.

$$\{F\} = [K]\{u\}$$

In the equation *F* denotes applied external load, *U* represent system behaviour and *K* is the property of material known as stiffness. In case of finite element analysis, each element is represented by different equation and finally makes thousand equations. For all cases, two variables are known and third one has to be determined therefore equation can be written as.

$$\{u\} = [K]^{-1}\{F\}$$

In this form above equation looks very easy and can be solved easily but these equations are interconnected at each node and their displacement, as well as force transmission, affects each other. The given below is case of single spring loaded and distort at both nodes by force $f_1$ $f_2$ and distorts by displacement $u_1$ *and* $u_2$ then equation can be written as

$$f_1 = -k(u_2 - u_1)$$
$$f_2 = k(u_2 - u_1)$$

These equations can be written in matrix form as

$$\begin{pmatrix} k & -k \\ -k & k \end{pmatrix}\begin{pmatrix} u_1 \\ u_2 \end{pmatrix} = \begin{pmatrix} f_1 \\ f_2 \end{pmatrix}$$

Or

$$[k_e]\{\mathrm{u}\} = \{F\} \quad \text{Whereas} \quad k_e = \begin{pmatrix} k & -k \\ -k & k \end{pmatrix}$$

Therefore for three springs in combination then,

$$\begin{pmatrix} k_1 & -k_1 & 0 \\ -k_1 & k_1 + k_2 & -k_2 \\ 0 & -k_2 & k_2 \end{pmatrix}\begin{pmatrix} U_1 \\ U_2 \\ U_3 \end{pmatrix} = \begin{pmatrix} F_1 \\ F_2 \\ F_3 \end{pmatrix}$$

In this way all the equation of discretised domain are connected, solved by Newton-Raphson method as follow.

$$X_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)}$$

**4. DESIGN AND MODELING**

Tyre coupling offers main advantage that it maintains high torque to lower weight ratio. The operating torque bearing capacity is around 12000 Nm. The considered model is capable of withstanding axial, lateral and angular misalignment up to 6 mm and 5 degrees. They can absorb abnormal shocks as well as minimize effect of misalignment and increase machines life. The torsional stresses are absorbed during the rotational motion of the shaft and smooth power transmission is achieved with less deflections. The flexible tyre coupling consists of two flanges and tyre is fixed between them. It has greater damping values as compared to rigid couplings. In order to carry out tyre coupling simulation three-dimensional models is developed in Pro-engineering software. Model is developed according to given specification. All the three components are first modelled in Pro-engineering modelling than they are assembled. The proposed system consists of a tyre coupling, assembling two flanges together and tyre attached in between. The design parameters of the CAD model are as under:

**Table.1 shows specifications of Tyre coupling**

| Maximum Bore | Length | Diameter | E | Weight | M | Screws |
|---|---|---|---|---|---|---|
| 90 | 230 | 194.5 | 89 | 67.2 | 26 | 8 |

Figure 1. Design of Assembly of tyre coupling.

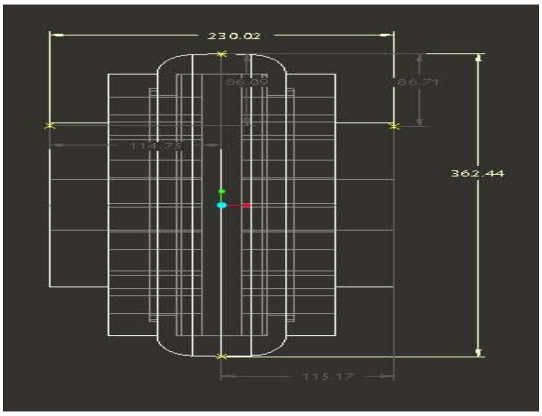


Figure 2. Two-dimensional model of tyre coupling.

**5. MESHING AND TRANSIENT ANALYSIS**

Finite element analyst and designers should be confident in the results of their analyses before sending a product to prototype or production. For that, it is mandatory to minimize errors in numerical solution. Among all the error discretization error is the major type of error because it greatly affects simulation results. In order to carry out structural analysis, finite element discretization method is

used to completely discretise physical domain. Simulation is conducted on unstructured mesh by using tetrahedron mesh elements to reduce discretization error. Patch conforming algorithm is used to refine mesh at critical points and to obtained high orthogonal mesh quality. Good orthogonal quality is achieved for getting accurate solution.

Finite element method uses numerical method to solve stiffness-displacement equations for every element iteratively. Newton-Raphson method is used to solve structural equations. For the simulation is tyre coupling is selected of which have rotational speed of 1800 rpm and the nominal torque values of 1881 Nm respectively. The maximum allowable misalignment cannot exceed 6 mm in parallel for this particular design. Transient structural analysis of tyre coupling is carried out in ANSYS 12.0 structural code. Material for flange and tyre are Grey Cast Iron Neoprene respectively. Since function of coupling is to transmit power by connecting two shafts, therefore, it is also designed like shaft. In order to conduct structural analysis, one end of coupling is fixed and moment is applied on other end then various parameters are determined. Moment is applied non-linearly with increasing time steps which is shown in Figure 3.

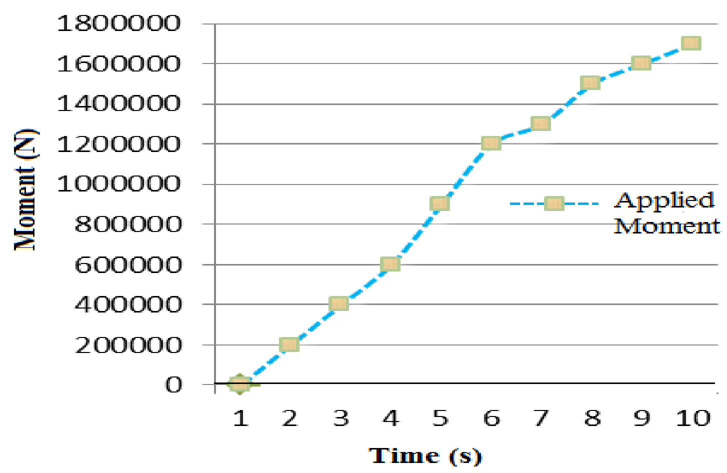


Figure 3. Applied moment variation

**6. MODEL ANALYSIS**

As coupling is highly important component of rotating system because its failure causes disaster of the system. There are several ways which can become cause of coupling failure such as excessive loading, misalignment, unbalance in system component and resonance. Therefore, coupling should be designed to withstand all these failure conditions. In this research, dynamic structural analysis is conducted to analyse structural integrity. As on structural analysis is not enough for safe, efficient and durable design of tyre coupling, therefore modal analysis is conducted to analyse effect of material damping, rotational speed as well as design of tyre coupling in order to resonance. Through modal analysis system mode shapes, natural frequencies, as well as the actual vibration response under this frequency range, can be predicted. Determination of natural frequencies is helpful to operate system at safer external frequencies to occurrence of resonance. The results from modal analysis can be used as reference value for other dynamic analysis like random analysis, harmonic analysis, etc. It is

analysed with different mode frequencies to prevent it from failure resulted by elastic strain. Hence the deformation and misalignment of the shaft is easily calculated. The following frequency input is given to the model:

**6. RESULT AND DISCUSSIONS**

Transient structural analysis of tyre coupling is carried out in ANSYS 12.0 structural code for flange and tyre are made up of grey cast iron and neoprene. The variation of maximum principal stresses incurred on tyre coupling is illustrated on Figure 4 whereas variation maximum shear stresses are demonstrated on Figure 5. The deformation in tyre coupling caused by applied load is illustrated on Figure 6 and its corresponding variation with time is shown in Figure 7. The von-Mises criteria of tyre coupling are illustrated on Figure 8 and 10 and variation in different stresses with time span are shown in Figure 9. The variation of tyre coupling frequency with span of time is illustrated on Figure 11.

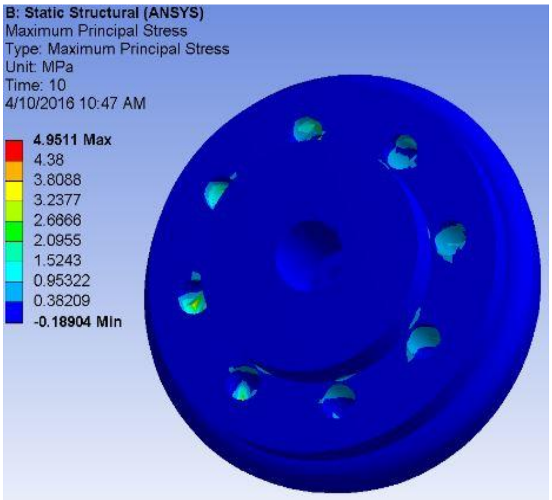


Figure 4. Principal stresses in tyre coupling

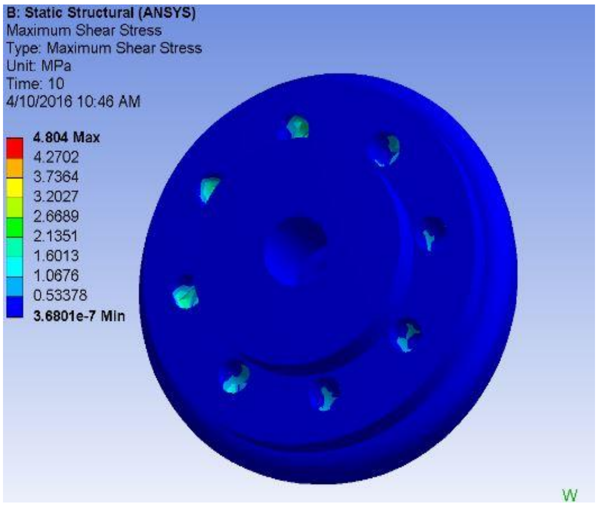


Figure 5. Shear stress variation

Fig. 4 exhibits the stress distribution in various sections of tyre coupling. In correspondence with maximum principal stress theory which holds for the brittle materials only where the grey cast iron behaves more or less likely brittle material. The theory states that the material will fail if principal stresses exceed the ultimate compressive and tensile stresses. In the light of this tyre coupling is subjected to 4.9511 MPa, which is very low as compared to maximum stress values hence it will remain safe for these specifications.

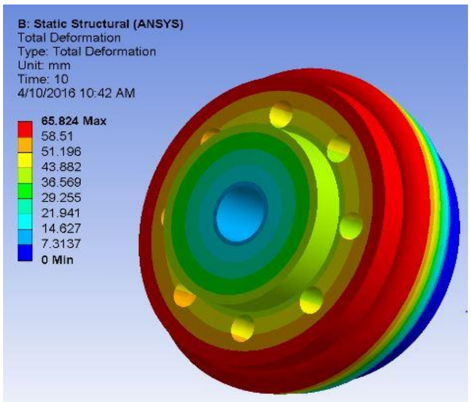


Figure 6. Deformation results in tyre coupling

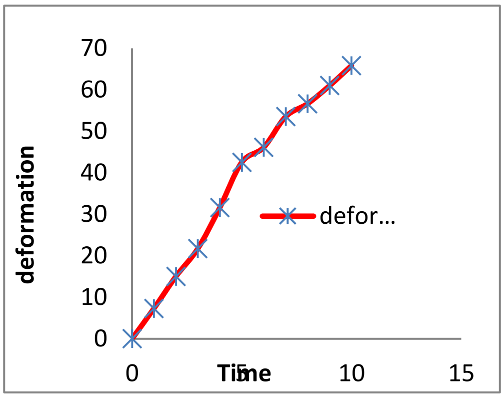


Figure 7. Variation in deformation V/s time.

Figure 5 shows the maximum shear stresses acting on coupling. According to the maximum shear stress theory criterion, a given structural Component is safe as long as the maximum value of the shearing stress in that component remains smaller than the corresponding value of the shearing stress. Therefore, it is clear in from analysis that tyre coupling is subjected to very shear stress as compared to maximum shearing stress of material, therefore, it remains safe.

Finite element analyses of tyre coupling results are shown in Figure 7 exhibits the deformation is caused by an applied load. In order to make conclusion about structure integrity St. Venants criteria is applied. Saint Venant's criterion states that structural component will remain safe as long as deformation or strain in that component will remain smaller than the ultimate strain at which tensile test specimen of the material might fail. The maximum deformation that the above test specimen can undergo is 65.82 mm which is quite less than the ultimate strain. Hence material will sustain the above load.

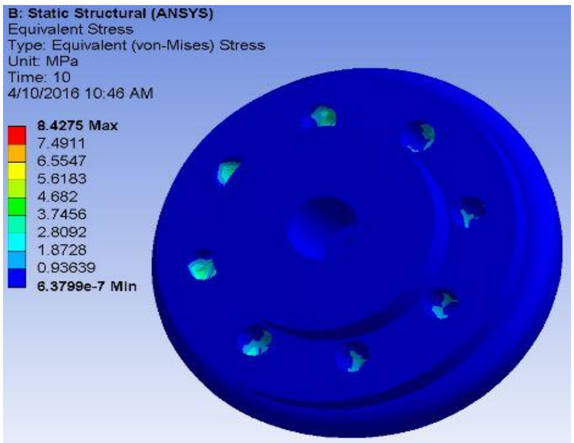


Fig 8. Analysis of equivalent stress occurs in tyre coupling.

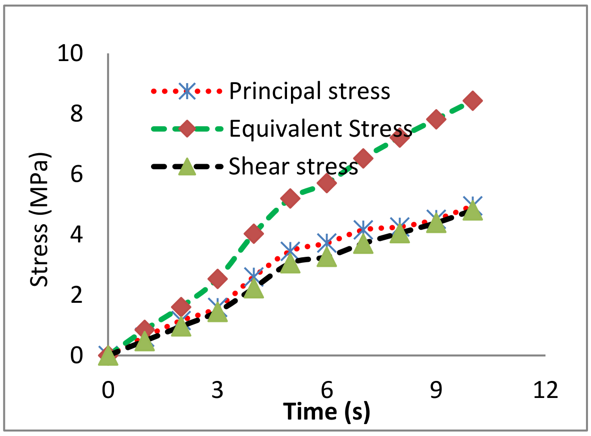


Figure 9. Variation in stresses against time.

Figure 8 shows the equivalent stresses acting on tyre coupling. From the values of stresses shown in figure indicate that given structural component is safe as long as the maximum value of the distortion energy per unit volume in above material remains smaller than the distortion energy per unit volume required causing yield in a tensile test specimen of the material. The distortion energy per unit volume in an isotropic material under plane stress corresponds to the principal stresses that are produced and are negligible comparatively the ultimate strength. It is shown in Figure 9 that the different types of stresses with the span of time increases as applied moment increases.

From the simulation, von-Mises, stresses are calculated in modal analysis which shows that with increase in operating frequencies the stress will increases proportionally. At the given mode frequencies, the induced stresses won't cause any failure as the maximum stress-bearing capacity of the material is very high.

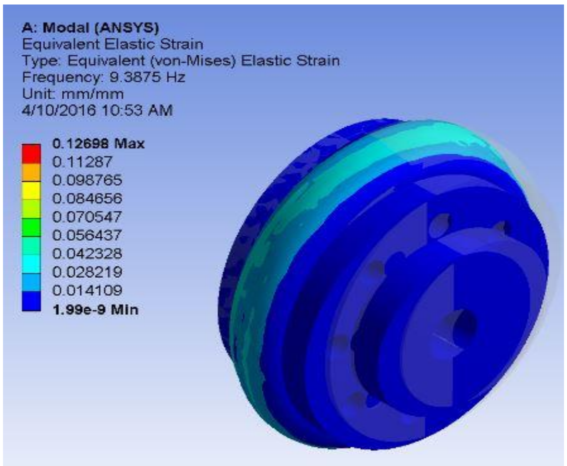


Fig 10. Analysis of elastic strain of tyre coupling.

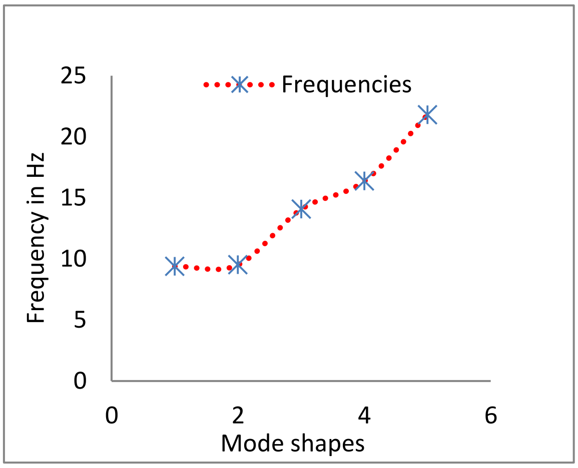


Fig 11. Effects of mode shapes on frequency.

In modal analysis, the input of moment is applied at the number of discrete frequencies over the range of our frequency interest. As the structure is excited its response will exhibit sharp peak at resonance frequency that is the input frequency. Meanwhile, the induced vibration will cause misalignment of shaft and the maximum misalignment turns out to be 0.12 mm under the above mode frequency.

In the Finite element modal analysis, tyre coupling is exposed to range of frequencies that induces stresses far less than the ultimate stresses. Moreover, total deformation obtained at the one mode frequency is 0.12 mm, whereas this type of coupling will operate nominally till 6 mm deformation. In order to prevent failures, the operating frequencies must not coincide with the input frequencies. However, the higher mode frequencies will prove to be critical as it can distort to the maximum strain of the coupling.

## Conclusion

The realistic tyre coupling model is presented and simulated in this study. The tyre between two flanges has been analysed while transmitting the torque and power. This study is conducted for transient loading to analyse structural as well as vibration behaviour of the tyre coupling in specific

for Neoprene material. Dynamic analysis of tyre coupling reveals that the considered tyre coupling design is safe from strength and vibration point of view. Because it is found that very small amount of stresses developed and natural frequencies are far away from external exciting frequencies. But the existing design and used material have very large deformation which became major cause of fatigue failure. It is also concluded that there is enough potential of weight reduction is available in existing design of coupling which increase system performance.

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